ROSAT **Calibrations**

Calculating Deadtime Corrections for *ROSAT* Data

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SUMMARY

This document discusses the calculation of `DEADTIME` corrections applied to *ROSAT* observations.
Intended Audience: Users of *ROSAT* data

LOG OF SIGNIFICANT CHANGES

Release Date	**Sections Changed**	**Brief Notes**
2011 Feb 2		Internal Draft
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1 INTRODUCTION

ROSAT, the Röntgen Satellite, was an X-ray observatory developed through a cooperative program between Germany, the United States, and the United Kingdom. The satellite was proposed by the Max-Planck-Institut für extraterrestrische Physik (MPE) and designed, built and operated in Germany. It was launched by the United States on June 1, 1990. The mission ended after almost nine years, on February 12, 1999. *ROSAT* carried two X-ray instruments on-board, the Position-Sensitive Proportional Counter (PSPC) provided by MPE, and the High-Resolution Imager (HRI) provided by the SAO/CfA in the US. A third instrument, an extreme ultraviolet telescope called the Wide Field Camera (WFC), was provided by the United Kingdom. After a commissioning phase, for the first eight months after launch, *ROSAT* carried out the first all-sky survey in the X-ray band with the PSPC, and in the extreme ultraviolet with the WFC. At the end of the first eight months and until the end of the mission *ROSAT* carried out pointed X-ray observations with either the PSPC or HRI; each X-ray field was also simultaneously observed by the WFC. More information on the ROSAT mission, its instruments, observations and data products can be found at the US *ROSAT* website, `http://heasarc.gsfc.nasa.gov/docs/rosat` (which also contains links to the German and UK *ROSAT* websites).

This document describes the calculation of `DEADTIME` for *ROSAT* observations. `DEADTIME` in general terms is a loss of exposure time produced because the detector needs some finite time to record, process and telemeter photon events. All analogue signals produced by the detectors take a time to process that is significant, especially when count rates are high. If a new photon arrives when the instrument is still processing a previous event, the new photon will not be recorded. Thus, because of this finite processing time, the true amount of exposure time is overestimated, and the true source count rate is underestimated. `DEADTIME` produces an effective loss of exposure time.

The `DEADTIME` correction should be recorded in any OGIP-compatible FITS rate files. The value of the `DEADTIME` correction can be given either as a keyword or as a column in the data table. A single keyword, `DEADC`, can be used only if a mean value applies to the entire observation. For binned data, storing the `DEADTIME` in a column (with FITS `TTYPEm = 'DEADC'`) is desirable if it varies with time (i.e., if it strongly depends on rapidly changing source count rate). If the `DEADTIME` has a strong dependence on energy, different keywords for all the different intensity measurements stored in the file should be given. If it is time and energy dependent, a column with an array representation in each row should be specified. The deadtime factor is unitless and has a value between 0 and 1. For more details, see the §4.8 of The Proposed Timing FITS File Format for High Energy Astrophysics Data (1994, Angelini et al., OGIP Memo OGIP/93-003), available from the HEASARC CALDB documentation library. However, in the particular case of *ROSAT* PSPC event files, the `DEADTIME` correction factor is given by the value of the `DTCOR` keyword in the Standard Event (`EXTNAME='STDEVT '`) extension of the event file (the "basic" file, `r*_bas.fits` file). The header of the `STDEVT` extension also provides the on-time and live-time values using the keywords `ONTIME` and `LIVETIME`, respectively. As discussed in Appendix B below, `ONTIME`×`DTCOR`=`LIVETIME`.

2 `DEADTIME` for the *ROSAT* PSPC

2.1 Sources of `DEADTIME`

According to the *ROSAT* User Handbook, the event dead time for the ROSAT PSPCs was estimated to be nominally $\approx 170\mu$s (the gate trigger time of a single event). However, analysis of ground calibration data have revealed that the PSPC dead time is a function of both the event pulse height (i.e., incident photon energy) and the incident count rate. There are also significant differences between the individual PSPCs (with the dead times for PSPC-A and PSPC-D systematically higher by 5-10% than those for PSPC-C and PSPC-B). The actual PSPC dead times are therefore in the range $180 - 280\mu$s. The dead time properties are not a strong function of position across the counters.

Most of the time, the PSPC dead time in orbit will be dominated by vetoed particle background events. For an individual detector and a single photon energy, the event dead time is well approximated by a linear function of count rate. Only at count rates > 600 counts s^{-1} are deviations sometimes found. Also, there is a 10-20% increase in the dead time between 0.28 keV and 1.47 keV. This is most likely due to an increase in the fraction of "double-triggers" (i.e., events that cause a second trigger due to wiggles in the decay of the initial pulse) with increasing pulse height.

2.2 Calculating `DEADTIME` for the PSPC

According to §4.2.2.8 of Appendix F, the dead time of the PSPC due to X-ray events was determined between 170μs and 280μs per event depending on pulse height; the dead time due to particle events is about 250μs. For "typical" ROSAT observations, i.e., observations with the total (accepted) X-ray event rate being less than 20 counts s^{-1}, deadtime will be almost exclusively caused by the count rate due to particle background events; for particle background rates of 100 counts s^{-1}, the dead time is 3% and for the maximal background rate of 400 counts s^{-1}, this increases to $\sim 12\%$. Note that while each recorded PSPC event is time-tagged, the electronics allows only an effective resolution of 130μs; this accuracy applies only to the relative arrival times of recorded events. The accuracy of absolute timing with respect to UT is on the order of a few milliseconds.

As described in Appendix A below, the `DEADTIME` correction factor for PSPC observations can be calculated by comparing the values of various event rates as recorded by the PSPC electronics and given in the event rate extension (`EXTNAME='EVRATE '`) of the PSPC "ancillary" file (`r*_anc.fits`). The relevant rates are listed below in Table 1. The `DEADTIME` correction factor can be decomposed into two parts, one produced by the PSPC electronics, and one produced by the loss of events due to a busy read-out when the cosmic event rate is high.

2.3 `DEADTIME` produced by the PSPC electronics

The PSPC electronics produces a `DEADTIME` factor (called "`FLIVE1`" in the source code in Appendix A, and which we call DTCOR1 here) which is given by the intrinsic `DEADTIME` factor of the PSPC per event (typically 250μs, but see the discussion above) multiplied by the count rate in the Lower-Level discriminator:

$$\mathrm{DTCOR1} = \sqrt{1 - \mathrm{A1LL} \times \mathrm{PSPC\_DTPE}},$$

where PSPC_DTPE is the PSPC `DEADTIME` per event and A1LL is the rate in the PSPC A1 Lower-Level discriminator. For a given PSPC observation the A1LL is given by the column named "A1_AL" (i.e. `TTYPE4 = 'A1_AL '`) in the event rate extension of the ancillary file. Typical values of PSPC_DTPE are 250μs, though as noted above this value can range between $170 - 280\mu$s.

2.4 Loss of events due to high count rate

The loss of events from the PSPC telemetry stream when the count rates are high can be determined from the ratio between the accepted and evaluated X-ray event rate (AEXE) and the accepted X-ray event rate (AXE). A difference between those two indicates loss of events in the telemetry stream because of a busy readout. This correction factor, which we call "DTCOR2" here, is given by

$$\mathtt{DTCOR2} = \mathtt{XTRANSM}/\mathtt{XACC},$$

where `XTRANSM` is the transmitted X-ray rate and `XACC` is the accepted X-ray rate.

Table 1: EXSAS-RFITS Rate Correspondence

EXSAS name	RFITS Column Name	RFITS TTYPE	Description
IA1LL	A1_AL	4	events in anode A1 above low-level thresh-hold, cts/s)
IAEXE	XTRANSM	3	transmitted X-ray rate
IAXE	XACC	7	accepted X-ray rate

2.5 The Total `DEADTIME` correction factor

The total `DEADTIME` correction factor, which is given by the keyword DTCOR in the STDEVT extension in the *ROSAT* "basic" FITS file, is simply

$$\mathrm{DTCOR} = \mathrm{DTCOR1} \times \mathrm{DTCOR2}.$$

3 Calculating DEADTIME for the *ROSAT* HRI

As discussed in Appendix F of the *ROSAT* Proposer guide, §11.6, the HRI has a processing dead time during which events may not be counted. This DEADTIME varies between 0.36 and 1.35 ms per event. The variation is discussed in §4.2.2 of Appendix F and depends on the fine position of the event. Thus there is a dead time correction that needs to be made for calculating the true event rate from a source. A mean dead time of $\rho = 0.81$ ms can be used for this purpose, and the true rate is then given by

$$n_t = n(1 + n\rho),$$

where n is the observed rate.

REFERENCES

G. Hasinger and S Snowden, 1990 TN-ROS-ME-ZA00/027

A The livtim.for Subroutine

The following PSPC subroutine is a verbatim reproduction of the routine `livtim.for` by G. Hassinger and C. Izzo and distributed with the 03OCT_EXP version of EXSAS, the MPE Midas analysis package for *ROSAT* data. This routine calculates the livetime factor for PSPC data based on X-ray event count rates and the deadtime parameter. As livetime is a factor between 0 and 1 which is multiplied by the exposure time to get the true ("DEADTIME-corrected" exposure time, the livetime factor returned by livtim.for is the same as the OGIP DEADC factor described above.

```
C @(#)livtim.for 2.1 (MPE-Garching) 10/15/98 11:30:34
      SUBROUTINE LIVTIM(A1LL,DEADTP,AXE,AEXE,FLIVE1,FLIVE2,FLIVE,IERR)
C
CC  Calculates PSPC livetime factor from Count Rates and Deadtime Param.
C
C************************ FFORM VERSION 1.2 ************ DD-MMM-YY HH:MM
C
```

```
CA  author : GRH        date: 13-MAR-1990 09:02
CU  update : IZZO       date: 04-SEP-1990 16:15 Implementation in EXSAS
C
CT  status: not tested
C
C   general description:
CG  The PSPC livetime factor, a value between 0 and 1) which has to be
CG  multiplied to the exposure time to obtain the effective live
CG  exposure time, is calculated from a product of two values:
CG
CG  FLIVE1 using the input A1-lower-level-discriminator count rate
CG  (A1LL) [cts/s] and the deadtime factor (DEADTP) [musec] according
CG  to the recipe in the TN-ROS-ME-ZA00-025. The deadtime parameter
CG  DEADTP, which is actually a function of mean energy and PSPC,
CG  should be specified from outside as a parameter. (Suggested value:
CG  250.0
CS NOTE THAT THE ESAS AND RASS ANALYSIS BY SNOWDEN USED 234.0
CG
CG  FLIVE2 from the ratio between the accepted and evaluated X-ray
CG  event rate (AEXE) and the accepted X-ray event rate (AXE). A
CG  difference between those two indicates loss of events in the
CG  telemetry stream because of a busy readout.
C
C   call_var.          type I/O description
CP  A1LL                R4  I   EE-A1LL count rate from HK-data [cts/s]
CP  AXE                 R4  I   EE-AXE  count rate from HK-data [cts/s]
CP  AEXE                R4  I   EE-AEXE  count rate from HK-data [cts/s]
CP  DEADTP              R4  I   Deadtime Parameter (ca. 190-260 [musec])
CP  FLIVE1              R4    O PSPC Livetime Factor (between 0 and 1)
CP  FLIVE2              R4    O ER Livetime Factor (between 0 and 1)
CP  FLIVE               R4    O Ttotal Livetime Factor (between 0 and 1)
CP  IERR                I     O = 0 no error
CP                              = 1 negative square root ARG (FLIVE1=1)
CP                              = 1 denominator = 0 (FLIVE2=1)
CP                              = 3
C
C   include_block_name          description
CI  R$COMMON:CGENL.CMN          general parameter common block
C
C   routines_called    type     description
CR  HFLAG               R       output flag handling routine
CR  WRFLAG              SR      writes to FLAG output stream
```

```
C
C   extensions/system calls     description
CX
C
C*********************************************************************
C
C   variables   meaning
C   ARG    argument under square root
C
      IMPLICIT NONE
C
      REAL        A1LL,AXE,AEXE,ARG,DEADTP,FLIVE1,FLIVE2,FLIVE
      INTEGER     IERR
      CHARACTER*8   RTNAME
C
      DATA          RTNAME /'LIVTIM'/
C
      IERR=0
C
C     FIRST: calculate PSPC livetime FLIVE1
C
      ARG = 2.0E-6 * A1LL * DEADTP
C
C     Check for error condition
C
      IF(ARG.LT.0.OR.ARG.GT.1)THEN
        IERR = 1
        FLIVE1 = 1.
        WRITE(6,*)
        WRITE(6,*) ' *** Unreasonable count rate or deadtime ***'
        WRITE(6,*)
      ELSE
        FLIVE1=SQRT(1.0-ARG)
      ENDIF
C
C     SECOND: calculate ER livetime FLIVE2
C     check for error condition
C
      IF(AXE.EQ.0.OR.AEXE.EQ.0)THEN
        IERR = 1
        FLIVE2 = 1.
      ELSE
```

```
          FLIVE2=AEXE/AXE
        ENDIF
C
C       THIRD: multiply the two values
C
        FLIVE = FLIVE1 * FLIVE2
C
        RETURN
        END
```

B Relevant FITS Header Keywords for Timing Information

The following keywords can express useful timing information in OGIP-compatible FITS event and rate files. These keywords are described more fully in HFWG Recommendation R11: On the Keywords and definitions relating to 'exposure-times' and their corrections, available from the HEASARC website.

TELAPSE is the time interval (in seconds) obtained as difference between the start and stop times of an observation. Any gaps due to Earth occultation, or high background counts and/or other anomalies, are included.

ONTIME is the total "good" time (in seconds) on source. If a Good Time Interval (GTI) table is provided, ONTIME should be calculated as the sum of those intervals. Corrections for instrumental `DEADTIME` effects are NOT included.

LIVETIME is the total time (in seconds) on source, corrected for the total instrumental `DEADTIME`. The ratio LIVETIME/ONTIME therefore gives the dead time correction value (given by the DEADC keyword, which hence lies in the range 0.0-1.0).

EXPOSURE is the total time (in seconds) on source, corrected for any relevant quantity used to calculate the corrected count rate. The value can include correction which are not directly related with time (e.g., collimation efficiency or vignetting). This keyword is a mean value when appropriate.

DEADC is the total correction factor for any dead time effect (i.e. LIVETIME/ONTIME), and lies in the range 0.0-1.0. Thus the multiplication of this value by the ONTIME value gives the effective integration time or LIVETIME (TIMEDEL in the case of a light curve). Since the total dead time of a given dataset can be the result of a multitude of instrumental/processing effects (especially related to the particular experiment, and/or processing by an onboard computer, and/or spacecraft operations), it is recommended that as well as including the total correction factor in the DEADC keyword, instrument-specific keywords are used to keep a record of the original value for the individual correction factors.